LA-UR -81-2003

CONF-810925--1

TITLE: CORRELATION METHODS

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MASTER

SUBMITTED TO: Sixth National Passive Conference
Portland, OR
September 8-12, 1981

Design Tools and Methods Seminar

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Form No. 836 R3
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UNITED STATES
DEPARTMENT OF ENERGY
CONTRACT W-7405-ENG. 36

CORRELATION METHODS*

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ABSTRACT

Correlation methods have been developed to provide a quick and relatively simple technique for estimating the performance of passive solar systems. The correlations are done with respect to "data" generated from simulation models. The techniques and accuracies are described. Both the Solar Load Ratio and Un-utilizability methods are described. The advantages and limitations of correlation methods as design tools are discussed.

1. INTRODUCTION

It is now generally accepted that computer simulation analysis using thermal-network type of mathematical representations of energy flows is an accurate method of predicting the performance of passive solar buildings. The analysis is generally done using hourly solar and weather data. This is fine if the designer has the computer, the capability, and the inclination to take this approach. But even under the best of circumstances it is costly and time consuming. Most designers ask for simpler techniques which are amenable to analysis using hand calculators in which estimates can be generated in a few minutes. Correlation techniques have emerged as a practical procedure which meet these requirements and give reasonable accuracy.

2. CORRELATION METHODS

In a correlation technique one seeks to relate the results in terms of one or more correlating parameters (generally dimensionless). Success is much more likely if the correlating parameters chosen preserve some essence of the overall physics governing the energy balances. The F-chart technique, which was developed at the University of Wisconsin for active solar systems, is an example of a correlation technique. In this case two correlating parameters were used. Independently, researchers at the Los Alamos Scientific Laboratory developed the Solar Load Ratio (SLR) method for active systems which utilizes one correlating parameter. Since then the SLR method has been applied extensively to passive solar systems and the University of Wisconsin has developed the Un-utilizability Method for passive systems.

These methods have two things in common. They use monthly weather data to predict monthly performance. A month has been found to be a particularly convenient time interval, being long enough that statistical variations tend to average out somewhat and short enough so that the basic weather statistics are stationary. Furthermore, only eight to twelve calculations are required in order to predict annual performance. The prediction of monthly performance leads to relatively high standard errors (±8%, typically) but annual performance is predicted with a standard error of only ±2%, typically. This is perfectly adequate for design purposes, being significantly less than the year-to-year variation which can be anticipated.

A second common feature of the methods is that the correlations are done using "data" developed from hour-by-hour computer simulations. In the case of F-chart, the TRNSYS code was employed and for the passive SLR correlations the PASOLE code was employed. Thus the correlation techniques are a second-generation analytical procedure, intended to give reasonably good correspondence with the simulation analysis. Their results are intrinsically no better than those obtained from simulations. The correlation techniques, however, require 200 to 2000 times fewer calculations to complete a yearly estimate and can be done using only a four-function calculator.

*Work performed under the auspices of the US Department of Energy, Office of Solar Applications for Buildings.

3. CORRELATION TECHNIQUES APPLIED TO PASSIVE SOLAR SYSTEMS

Two different correlation methods will be described, the Solar Load Ratio method developed at the Los Alamos National Laboratory and the Un-utilizability method developed at the University of Wisconsin. The SLR method is quite a bit easier to use but is more restricted in the number of different system parameters which can be specified. The Un-utilizability method can be programmed easily into a microcomputer and is somewhat more general.

3.1 The Solar Ratio Method (SLR)

The SLR method has been applied extensively to a variety of passive systems. A different correlation is required for each different passive system configuration. The method is the basis for the design techniques described in the DOE "Passive Solar Design Handbook, Vol. II, Passive Solar Design Analysis"[1] and the results are being widely used within the passive solar design community. A variety of hand-held calculator and microcomputer routines have been written using the methodology and many are for sale.

The parent set of monthly performance data for the SLR correlations is generated using the PASOLE hour-by-hour computer simulation code. The method depends on the use of a single correlating parameter (SLR) defined as follows:

SLR = (solar absorbed)/(net reference load)

As mentioned, the correlation time is one month so that each of the parameters in the above equation are for a one month period. Both the numerator and denominator of SLR are in energy units so SLR itself is dimensionless. Physically it relates the monthly solar energy available to the building to the net load which would be experienced by a comparable building without the passive solar element.

The parameter which is correlated is the solar savings fraction, SSF, defined as follows:

SSF = 1 - (auxiliary)/(net reference load)

The definition of the terms used in these two relations is important, but it is not the purpose here to discuss this in detail. The various terms are defined in the Passive Solar Design Handbook where the distinctions between various ways of estimating load are discussed. The key point is that the solar savings fraction is intended to identify the savings due to adding a particular passive solar element on a building. The net reference load is the heating requirements of the non-solar elements in the building. This gives the savings due to solar because in a non-solar building presumably the solar element would be replaced with a normal wall with the normal complement of windows.

In developing the correlations, a functional form was used which allows the selection of four different coefficients. These were adjusted in order to obtain a least-square error in the annual solar savings fraction.

Typically the correlations are done using the monthly results of hour-by-hour calculations from many different cities with four different values of building load coefficient in each city. This gives a reasonably diverse ensemble of "data" points. The standard deviation of the error in prediction of solar savings fraction, compared to the hour-by-hour simulations, is typically about 2 to 4%.

3.2 Reference Designs

The hour-by-hour simulations which are used as the basis for the SLR correlations are done with a detailed model of the building in which all of the different design parameters are specified. The only design parameter which is changed is the ratio of the glazing area to the building load coefficient (the Load Collector Ratio, LCR). Typically about four different values of LCR were chosen so that the correlation should adequately reflect variations in this key parameter.

The correlations do not allow the designer to estimate performance variations due to changes in any of the many other design parameters. Thus the correlations relate only to the reference design used in the simulations.

One way to overcome this difficulty is to use sensitivity calculations which have been done using the hour-by-hour simulation codes. The procedure is to perform a series of year-long simulations for different values of one of the design parameters, holding all other parameters at the reference level. These results are generally presented in graphical form and allow the designer to see the effect of changing one particular design parameter. This procedure is followed for each of the different design parameters. A major part of the Passive Solar Design Handbook is taken up with such sensitivity studies for the direct gain and thermal storage wall systems.

Another possibility is simply to provide enough different SLR correlations for different selections of design parameters that one can come reasonably close to the intended design or bracket the calculation with two SLR estimations. This approach is quite practical. Since the publication of the "Passive Solar Design Handbook" the number of correlations which have been developed has been expanded from the original six to 94 different configurations.

Nine different direct-gain correlations have been developed representing different numbers of glazings, different values of storage surface-to-glazing area ratios, and different wall thicknesses. Fifty-seven different thermal storage wall correlations have been developed representing Trombe wall and water wall, use or non-use of night insulation, different numbers of glazings, use or non-use of a selective surface, different Trombe wall thicknesses and thermal conductivities, different water wall masses, and both vented and unvented Trombe walls. Twenty-eight different sunspace correlations have been done representing three different configurations, glazed and unglazed end walls on the linear configurations, use or non-use of night insulation, and masonry wall or water drum storage. The availability of these different correlations should satisfy most of the concerns which have been voiced about the limitations of the SLR technique.

It should be noted that the form of the correlations has been modified slightly to provide for a more flexible definition of the sunspace geometry in order that both the building load coefficient and the sunspace load coefficient can be entered separately.

3.3 Example of SLR Correlations

As an example of the correlation results, the following graphs give the simulation results (Fig. 1) and correlation accuracy (Fig. 2) for one reference design, the case of an attached sunspace with sloping glazing (50 degrees), masonry thermal storage between sunspace and house, opaque end walls, and no night insulation.

3.4 Direct-gain Report

A report describing the major amount of work accomplished on direct-gain systems has been written by William Wray and is in the publication pipeline at Los Alamos.[2] It should be available in the near future.

3.5 The Un-utilizability Method

The Un-utilizability design method developed at the University of Wisconsin was originally applied to direct-gain systems and more recently has been applied to thermal storage walls.[3] In this method the monthly average auxiliary energy requirements of a building are estimated using upper and lower

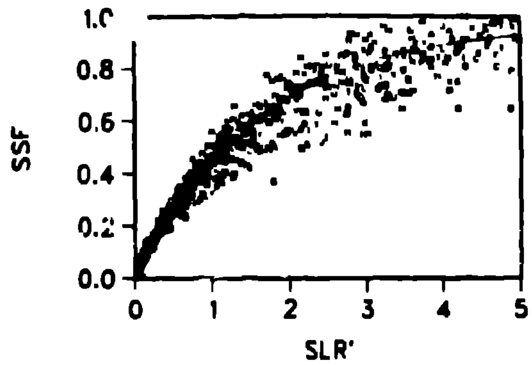

Fig. 1. Monthly SSF vs SLR'. The different letters refer to different cities.

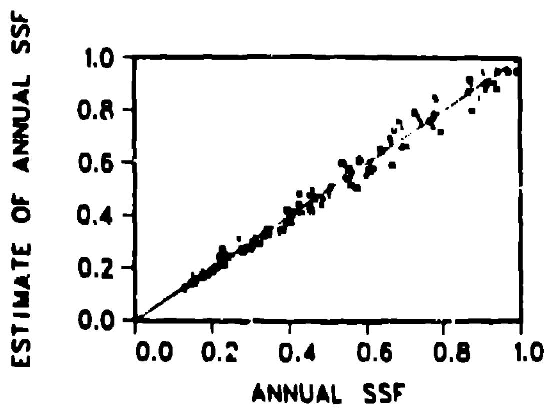

Fig. 2. Comparison of annual SSF estimated by SLR method and calculated by simulation. The standard deviation of the error is 0.032 over an ensemble of four LCR's each in 24 cities.

theoretical limits to system performance. An empirical correlation is presented for the fraction of the load met by the thermal storage wall for systems that fall between these two bounds. An advantage of this method is that it offers a much larger range of design parameters.

The lower limit on auxiliary energy use is when the building has infinite thermal storage capacity. In this case all of the net solar gain can be used at some point during the month.

The other extreme is a hypothetical building having no energy storage capacity in either the building or the thermal storage wall. This case represents the upper limit of actual auxiliary energy use. The equations for both the upper and lower limits are relatively simple (compared to a simulation, for example).

Once these two limits have been established then the performance of the actual finite thermal capacity system can be determined using a correlation. An example of the results for this method taken from Ref. 3 is shown in Fig. 3. In this figure F is the solar savings fraction, F_∞ is the infinite thermal capacity result, and Y is the ratio of the storage capacity of the building and wall to the energy which must be dumped in a building having zero capacity. The correlation for F can be represented either graphically as in Fig. 3 or analytically.

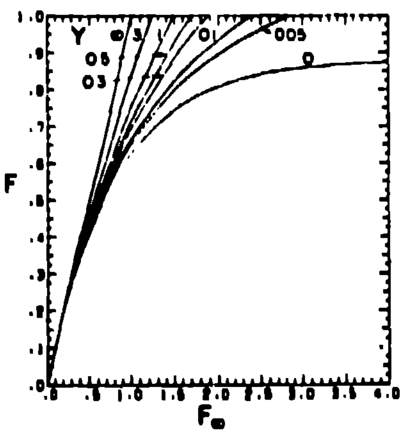

Fig. 3. Un-utilizability Correlation.

The authors of the Un-utilizability method have compared results with the SLR technique by setting the system parameters to be the same. This comparison shows that the auxiliary energies predicted by the two techniques are extremely close.

4. PERFORMANCE TABLES FOR PARTICULAR LOCATIONS (ANNUAL METHOD)

Since the correlation curves are developed using weather data from a variety of different locations, these curves can be used in locations which have a climate type encompassed by the original grouping of cities. However, an annual solar savings fraction calculation involves summing up the results of twelve monthly calculations. For a particular city the results depend only on the ratio of building load to collector area (LCR), on the system type, and on the temperature base used in the calculation of the degree days. Thus it is possible to make up tables for a particular city which relate the solar savings fraction to the LCR for the various systems, assuming one particular base temperature. These tables are much easier to use than the SLR correlations.

LCR tables have been made up for 216 different locations in the U.S. and southern Canada based on the SOLMET weather data. These are published in the Passive Solar Design Handbook, Appendix F, for direct gain and thermal storage wall systems. These tables form the basis of a simplified design procedure described in the Handbook.

5. MIXED SYSTEMS

A simple methodology has been developed for dealing with mixed systems when using the SLR method. The technique treats the house building load coefficient as if it were divided into two portions in the same ratio as the relative glazing areas of the two passive system types. This amounts to the simple assumption that each of the system types serves a portion of the load with no exchange of heat across an imaginary boundary within the house. Normally one would expect that transfers which do take place would be beneficial and therefore the calculations based on this assumption might be somewhat conservative.

6. PERFORMANCE VARIATION DUE TO LIVING HABITS

All of the simulation analyses used to develop the correlations are based on a building which is used in a very specific and regular manner. The auxiliary heating thermostat is assumed to be set at a particular fixed level (generally 65 F). A 10 F floating band is assumed. If the temperature in the house exceeds the thermostat setting by more than 10 F then it is assumed that the excess energy is vented so as to maintain the temperature less than or equal to the upper setting. This energy is not stored and is therefore lost.

It is well known that the manner in which the house is operated greatly affects the energy consumption. The thermostat setting for auxiliary heat is by far the most important effect. This shows up clearly in the sensitivity analyses. For example, a thermostat setting of 70 F (which might correspond to a degree day base temperature of 65 F, accounting 5 F for the effect of internal generation) might result in an auxiliary heating requirement of 8.2 million Btu/year for a 1500 sq ft house in Dodge City, Kansas. This is a house designed for 78% solar savings fraction (the example problem in the Passive Solar Design Handbook). If the thermostat were set at 75 F instead, the auxiliary heating would be 14.2 million Btu; or, if the thermostat were set at 60 F, the auxiliary heat needed would be about 2.2 million Btu/year.

Therefore, in interpreting the results from monitored buildings, or in predicting the performance of new buildings, one must be very careful to specify the operating conditions.

Other operating characteristics of the house can also be important, such as, 1) if movable insulation is provided for the house, then it is important to know how it is operated, 2) a family with many small children may experience larger infiltration due to multiple door openings, 3) a house with doorways connecting between the living areas and a sunspace might be much more comfortable if some attention is paid to the appropriate opening and closing of these doors.

7. DECIDING BETWEEN CONSERVATION AND PASSIVE SOLAR OPTIONS

A simple technique has been developed which can be used to determine the optimum mix between conservation and solar strategies.[4] In order to obtain an answer, the cost characteristics of both the passive solar aperture and the energy conservation features are needed. This information will generally be in the form of the cost per R per sq ft for the wall and ceiling insulation, the cost per additional glazing for windows, the cost of reducing infiltration (including the cost of adding an air-to-air heat recovery unit if needed) and also the cost per sq ft for the passive solar collection aperture. Given this information the method provides simple equations which can be used to trace out the optimum-mix line for a particular locale.

8. CONCLUSIONS

Correlation methods of prediction have advantages in greatly simplifying the time and complexity of performance predictions. Their accuracy is generally adequate for design purposes provided they are applied to buildings which correspond reasonably closely to the reference designs used in developing the correlations. The most simplified correlation procedures are amenable to use with hand calculators, especially if pre-calculated tables are available corresponding to the weather data for the location of interest. When reporting the results of these calculations, the designer should be especially careful to specify the range of validity of the analysis, especially as pertains to both operating characteristics and design parameters.

Correlation techniques are especially amenable to use in microcomputer routines which can be used in a design office. Very quick answers can be obtained during the schematic design and design development phases of a building to aid in deciding between different design options. This would include trade-offs between various conservation options and passive solar options.

9. ACKNOWLEDGEMENTS

The author gratefully acknowledges the assistance of James Hedstrom, Robert McFarland, William Wray, and Dennis Barley in the development of the SLR correlation techniques.

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